AMPTE/CCE-CHEM-based estimation of the ring current electric field and associated particle drift paths during typical solar minimum times

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ABSTRACT

Study of the electric field configuration in the Earth's magnetosphere is crucial for understanding the dynamics of magnetospheric plasmas, and in particular that of the ring current. Here, we present empirical equipotential patterns derived from the mean kinetic energy of equatorial particles as reconstructed from the empirical model proposed by Milillo et al. 2000. The model reproduces the proton distributions according to the most probable magnetic activity conditions during solar minimum periods. From this statistical distribution, we reconstruct the pattern of electric field equipotential in the equatorial plane, assuming total energy conservation. A comparison between the proposed model and other models in literature is shown. We compute single particle drift paths at different initial energies and positions, and we focus on both open and closed drift paths and examine well-established observational features such as dawn-dusk asymmetries of particle transport or flux depletions at specific energies (ion gaps) in energy-time spectrograms.

AMPTE/CCE DATA SET

Mission lifetime: August 1984 – December 1988

Perigee 1.2 R_E , Apogee 8.8 R_E

Orbital inclination 4.8^o

CHEM data set used for the database

Years: January 1985-June 1987

$3 < L < 9.25$ $\Delta L = 0.25$

1.5 keV < E < 300 keV 32 logarithmic steps

$80^o <$ Pitch angle $< 100^o$

0 MLT 23 ΔMLT = 1

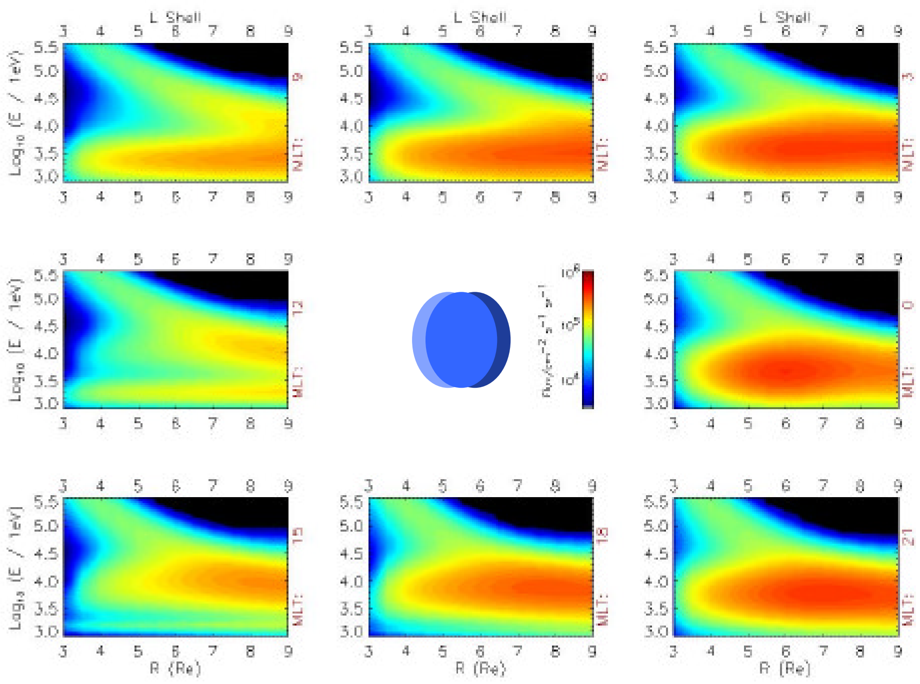
AE < 100 nT

The obtained data-set is not simply an average of the magnetospheric proton distributions, neither a reproduction of any actual magnetosphere corresponding to a precise storm phase. By excluding the periods with AE > 100 nT, this data-set reproduces an average of the most frequent configurations of the magnetosphere during solar minimum.

MODEL

The model is obtained through the elaboration of an analytical form coming from iterative best-fit techniques (Milillo et al., 2000). It reproduces the average H^+ fluxes at 90^o pitch angle in the equatorial magnetosphere in the L-shell range between 3 and 9.25 and in the energy range of the AMPTE/CCE-CHEM data (1-300 keV).

The **figure 1** shows the modelled proton fluxes as computed by using a subset of the fit function for eight MLT.



MAGNETOSPHERIC PARAMETERS

The model provide an overall picture of the magnetosphere plasma distributions, thus allowing estimates of the major physical parameters.

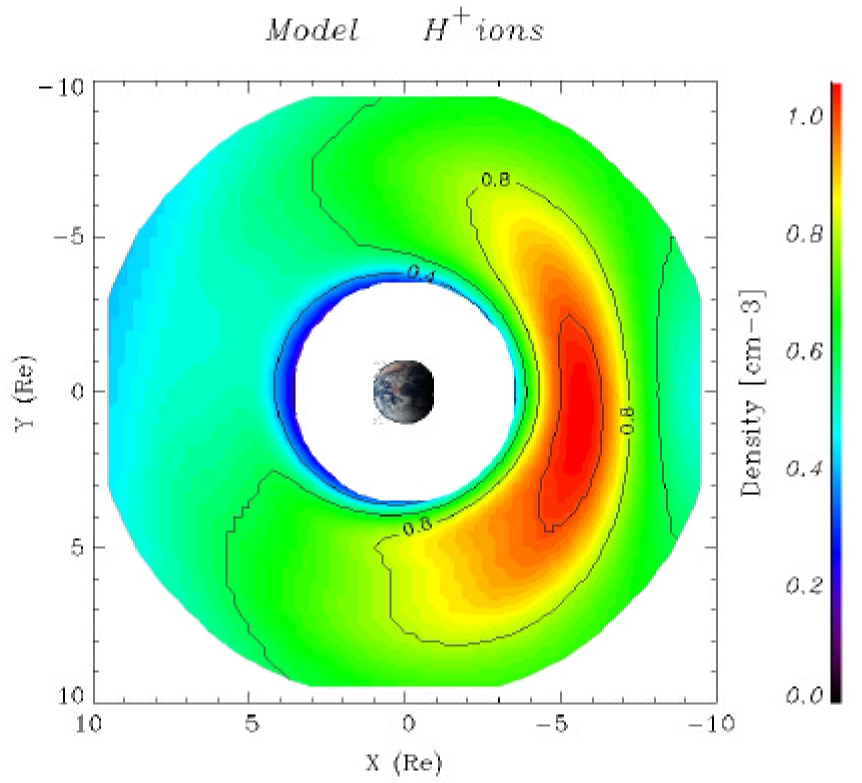
❖ The velocity distribution function f(v) is related to the differential flux *f* through the following expression:

$$f(v) = f\, m\, v^{-2}$$

where m and v are the particle mass and the flow velocity respectively.

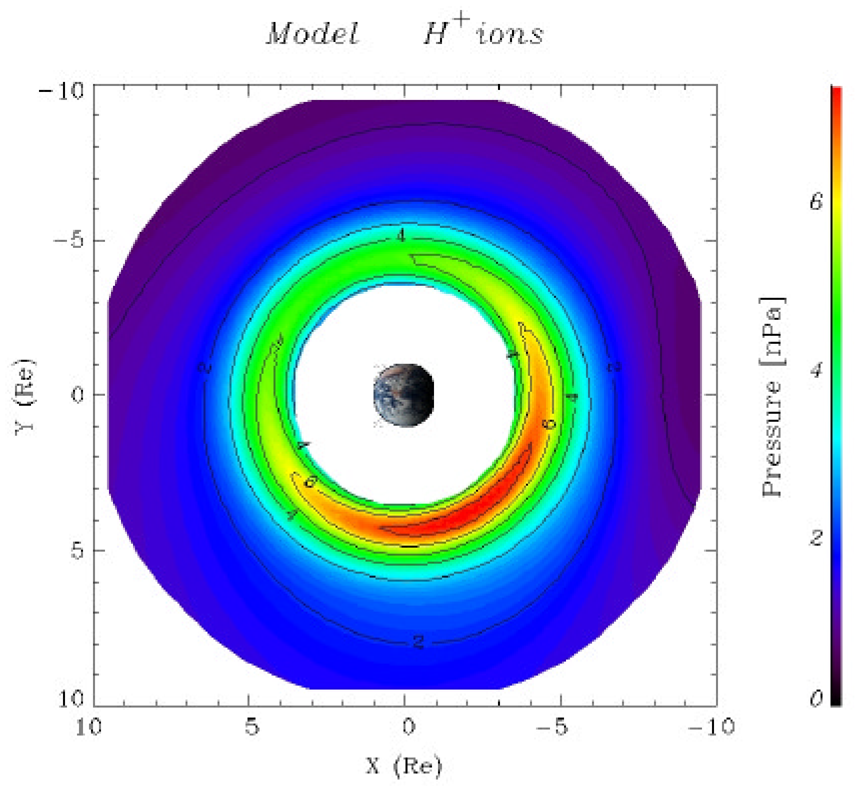
If we assume an isotropic flux, that is, a flat pitch angle profile, we can derive the following quantities:

❖ **Fig. 2**. Particle density = $N = 4\pi \;\; f(v)\, v^{2}\, dv$

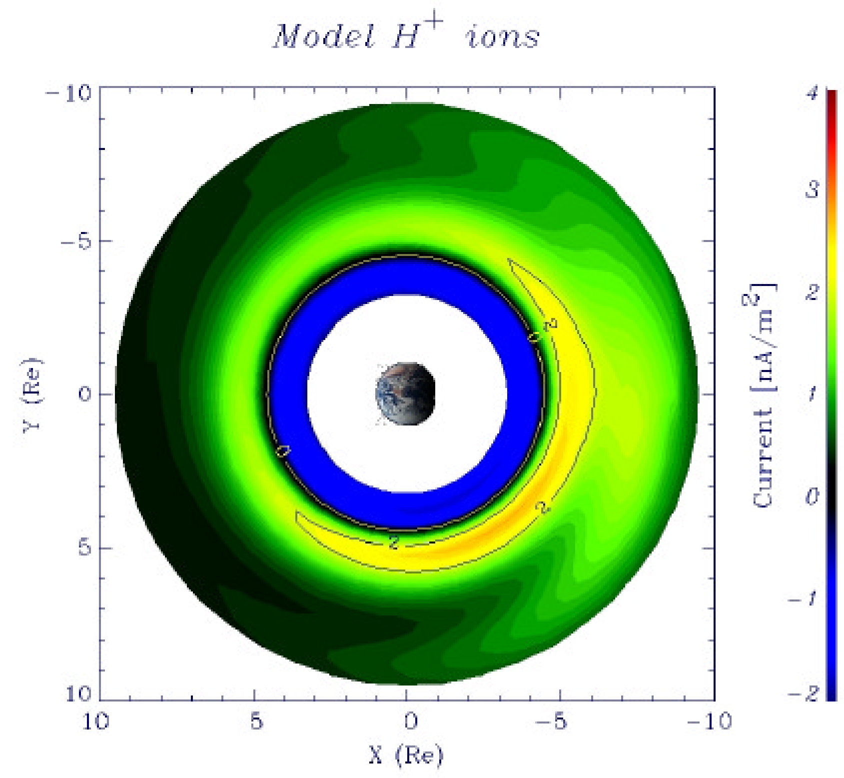


❖ Energy density = $e = m2p\int f(v) \cdot v^{4} \cdot dv$

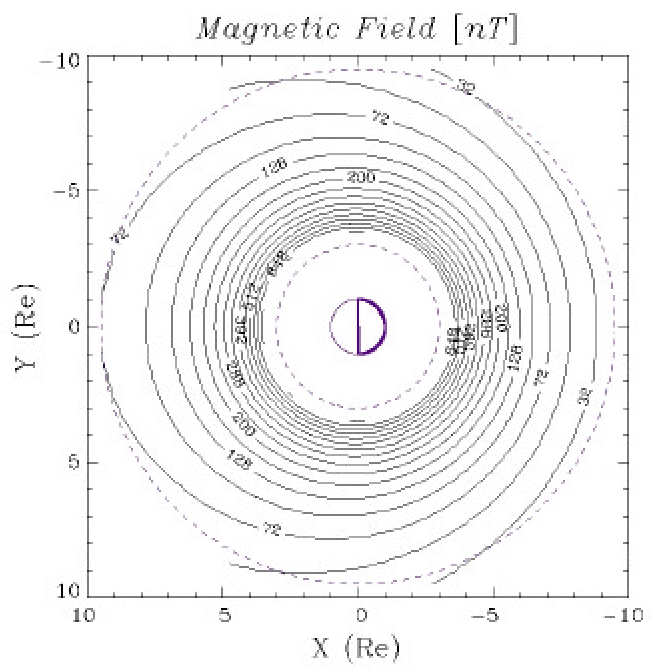
❖ **Fig. 3**. Normal pressure = $P_{\perp} = \frac{2}{3}e$



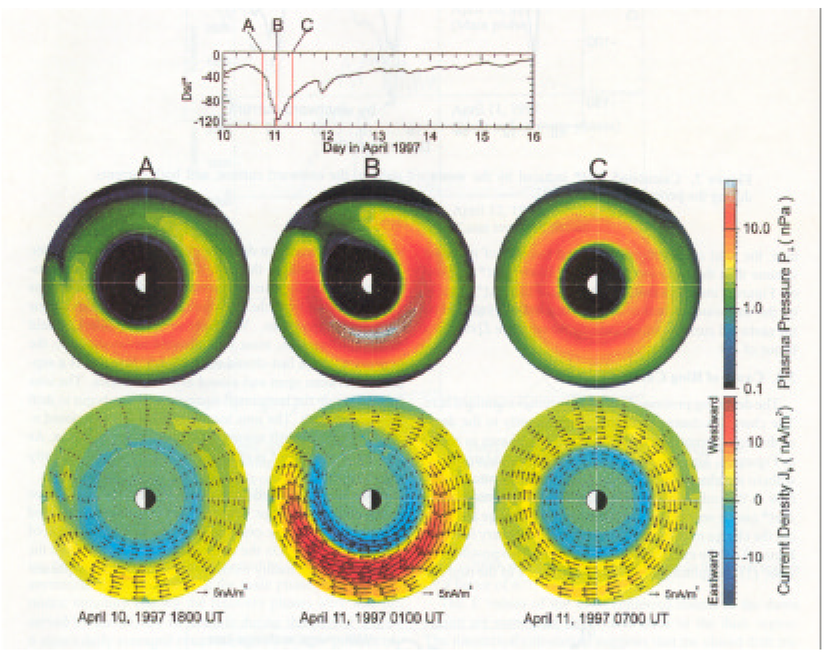
❖ **Fig. 4.** Normal current = $J_{\perp} = -\frac{1}{B}\frac{\partial P_{\perp}}{\partial l}$



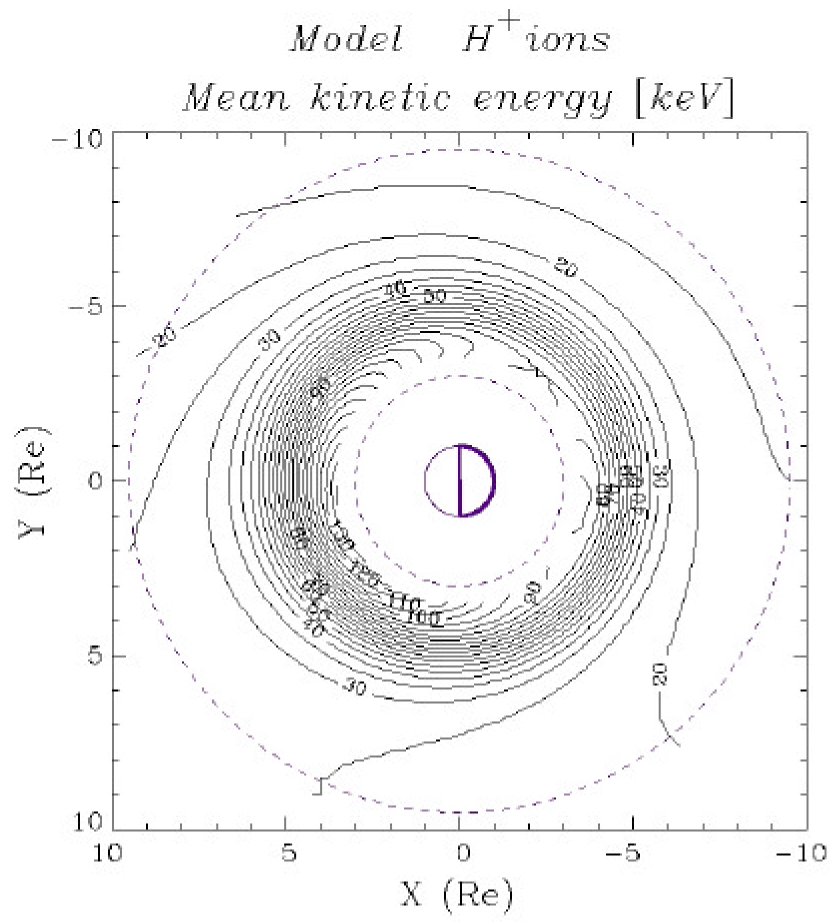
The equatorial magnetic field *B* as modeled by McIlwain (1972) has been applied for the computation of the current contours (**Fig. 5**).



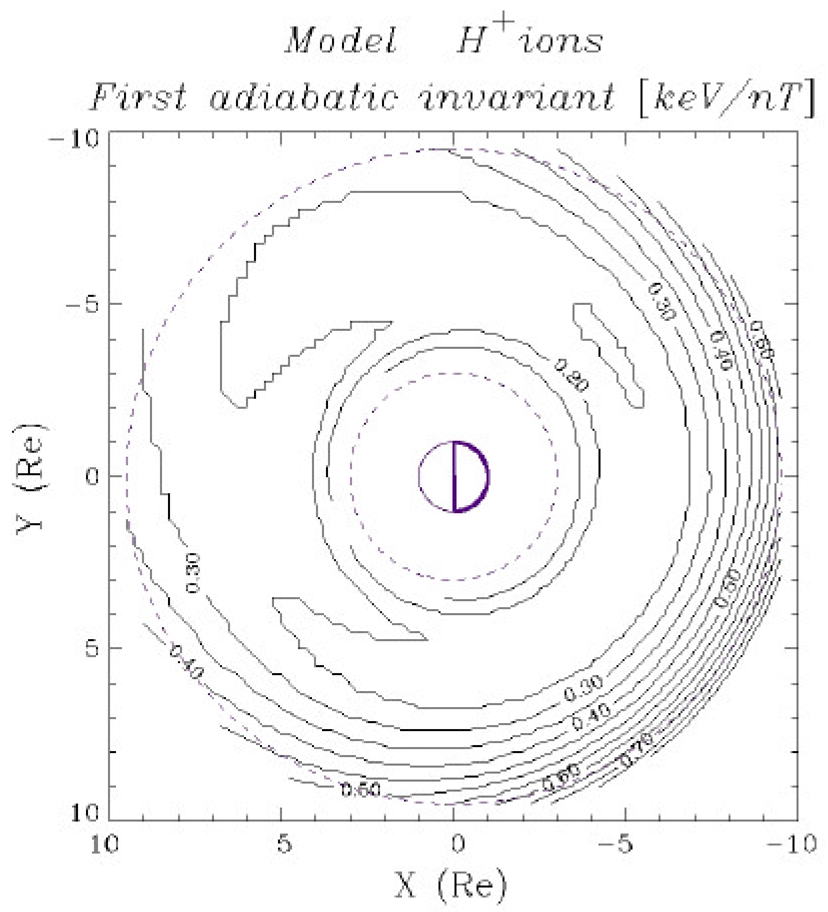
We can see that these results are consistent with the simulations of the normal pressure and current associated to storm development computed by Ebihara and Ejiri (2000) (**Fig. 6**).



❖ **Fig. 7**. Mean kinetic en. = $\overline{E} = \frac{1}{2} m \frac{\int f(v) \cdot v^4 \cdot dv}{\int f(v) \cdot v^2 \cdot dv}$



❖ **Fig. 8.** First adiabatic invariant at 90^o = $\overline{m} = \frac{\overline{E}}{B}$



GLOBAL ELECTRIC FIELD ESTIMATION

Let us make the following assumptions for a quiet time magnetosphere:

- there is no electric field parallel to B;
- the electric and magnetic fields are time independent;
- the particle motion is adiabatic: particles not involved in loss processes maintain constant the first magnetic moment (*m*) and the total energy;
- the whole inner magnetosphere is populated by proton distributions that have the same total energy. This is true if the protons originate from a localized region with a narrow energy distribution.

In this case we can argue that particles with similar energies originating from neighbouring regions are transported towards similarly localized regions in the inner magnetosphere. Hence, we may establish a more or less direct relationship between initial and final energies as well as regions of space. The contour shown in Fig. 8 implies that all the particles in the magnetosphere have similar magnetic moment. This give confidence of the last hypothesis of similar total energy (*W*) given by the sum of the kinetic energy (*E)* and the electric potential (*U*) energy:

$$W = E + qU$$

If the particles move in the magnetosphere without total energy variation, then a variation of the electric potential produces a variation of the kinetic energy:

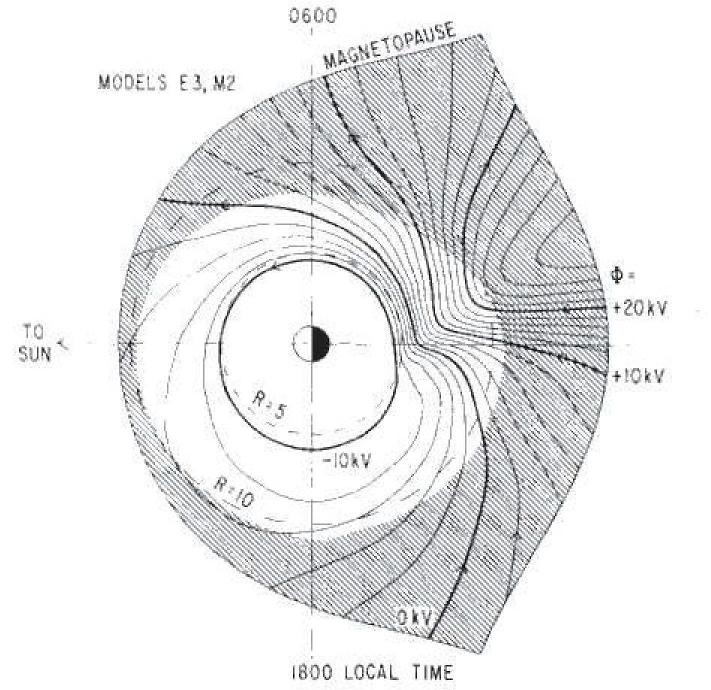
$$\boxed{\Delta E = -q\Delta U}$$

Hence, the equipotential lines of the mean kinetic energy have the same shape of the electric equipotential lines (see Fig. 7).

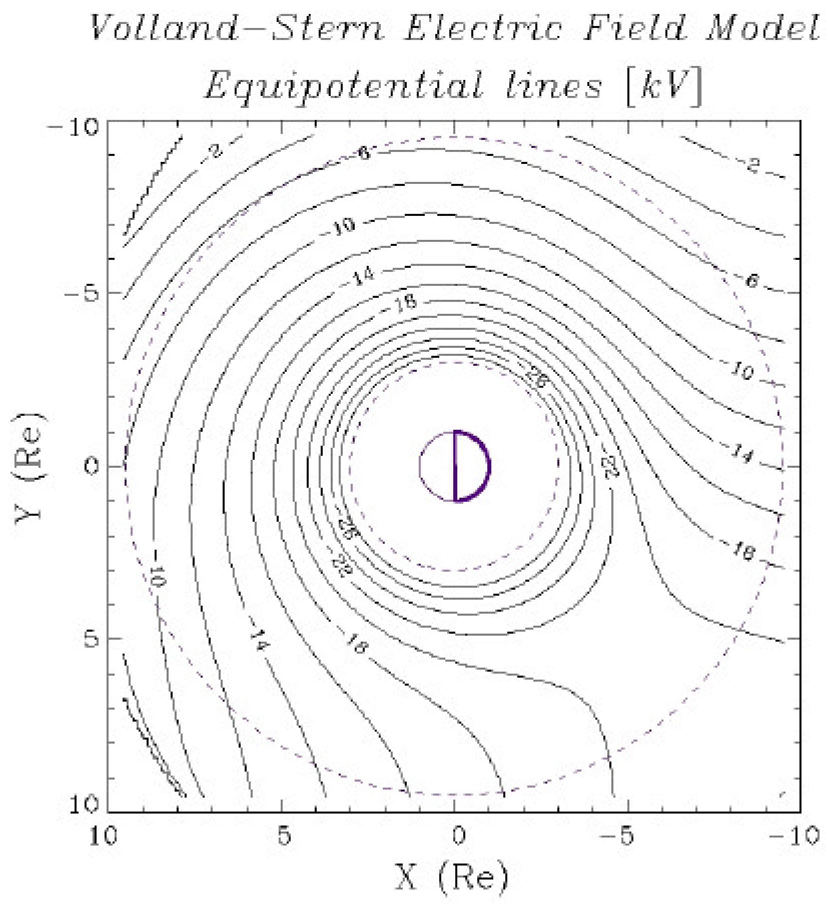
However, the particle distributions do not conserve the total energy in the whole magnetosphere, due to the loss processes. If we consider the major loss processes in the magnetosphere, we can see that charge-exchange acts at low energies and low *L*-shells (Daglis et al., 1999). The Coulomb collision acts in a similar way, but with a minor contribution (Ebihara et al., 1998). The wave-particle interaction acts at higher energy but, with a minor contribution during quiet time (Daglis et al., 1999).

If these assumptions are verified, the electric field equipotentials in the inner magnetosphere can be reconstructed in a straightforward manner in the outer regions (*L*-shell > 5).

As a matter of fact, there is a very good agreement between the modelled mean kinetic energy equipotential lines and the empirically derived electric potential lines mapped by McIlwain (1972) (**Fig. 9**).

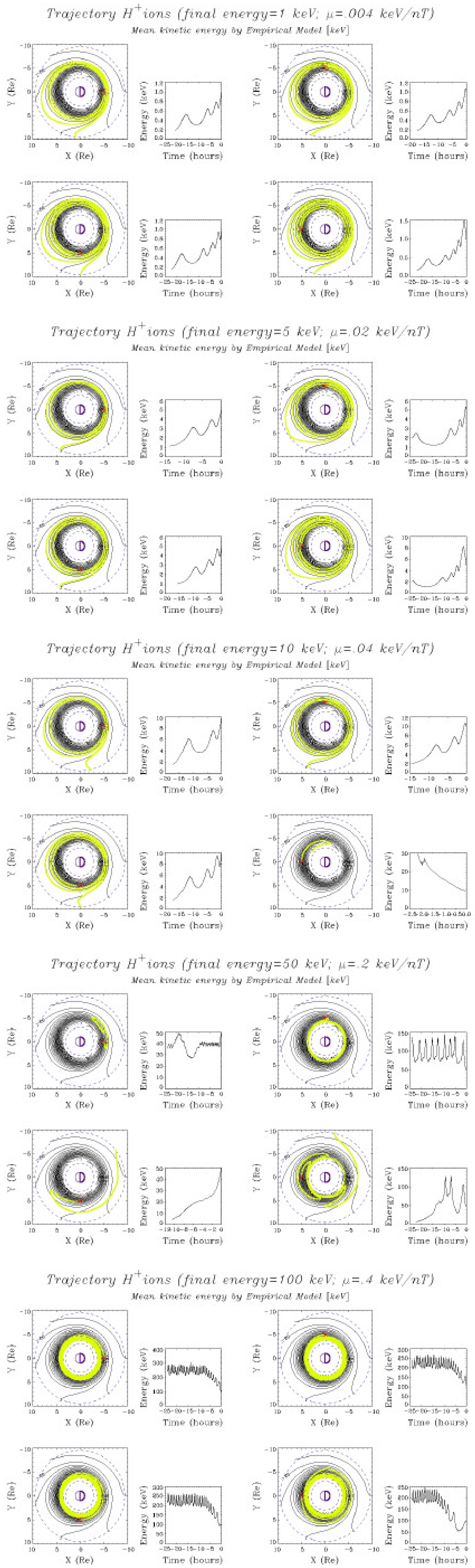


Inside the *L*-shell = 5 the equipotential lines are concentric due to the corotation electric field (**Fig. 10)**.



PARTICLE DRIFT PATHS

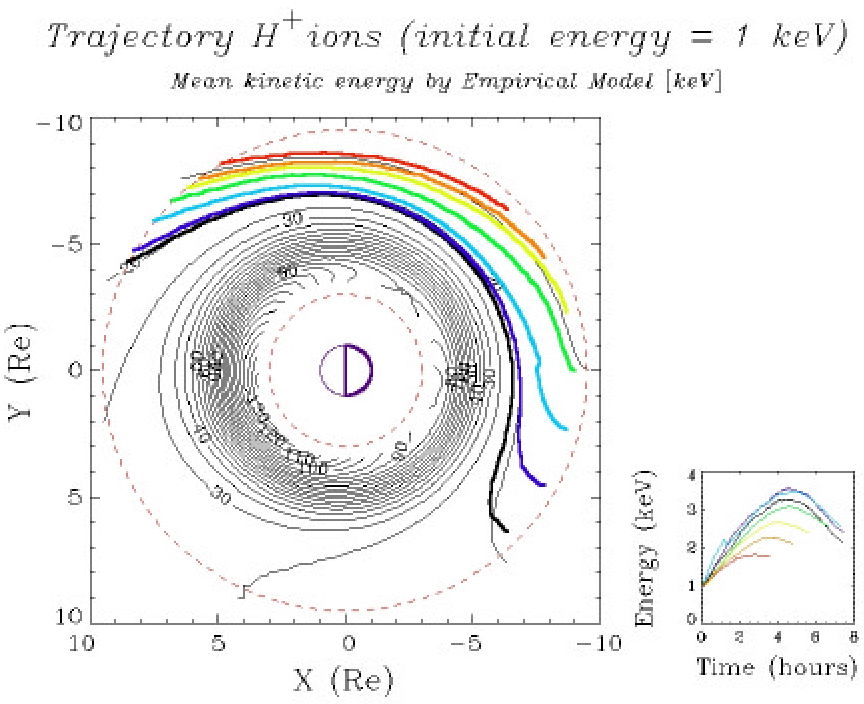
We have applied this electric potential model together with the magnetic field model by Tsyganenko (1989) to particles at final position 5 R_E and MLT 0000, 0600, 1200, 1800 and different final energies (**Fig. 11)**.

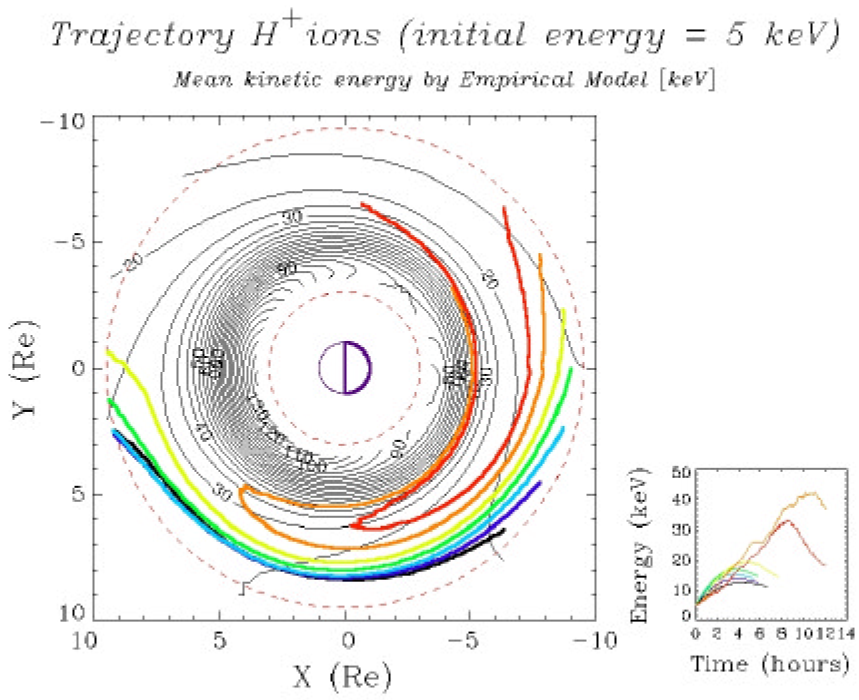


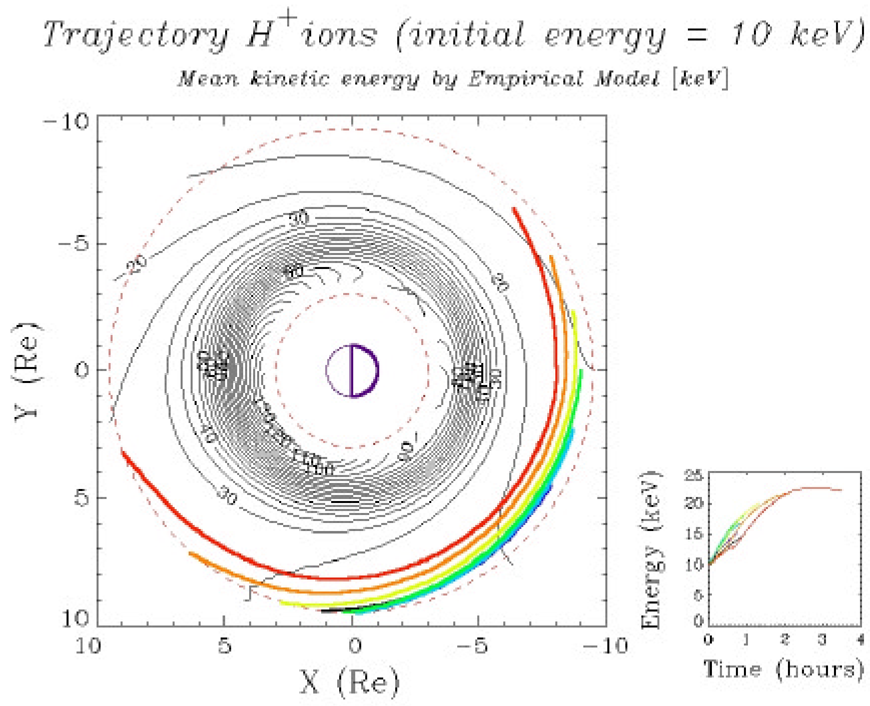
The trajectories suggest a source in the day-dusk sector between MLT 1600 and 1900 with an energy range between .2 and 2 keV.

Around 50 keV at 5 Re the backward trajectories shown in fig. 11 seem not realistic, especially at MLT 0000, 0600, 1200. For instance a hypothetical 50 keV particle located at MLT 0000 should unrealistically escape from the equatorial ionosphere. This suggests a depletion around this energy, well supported by the modelled fluxes.

The night-side particles have open trajectories (**Fig. 12**) in agreement with the observed butterfly shaped pitch angle distributions of the night-side particles at *L*-shell more than $L = 7$ (Fritz et al., 2000).



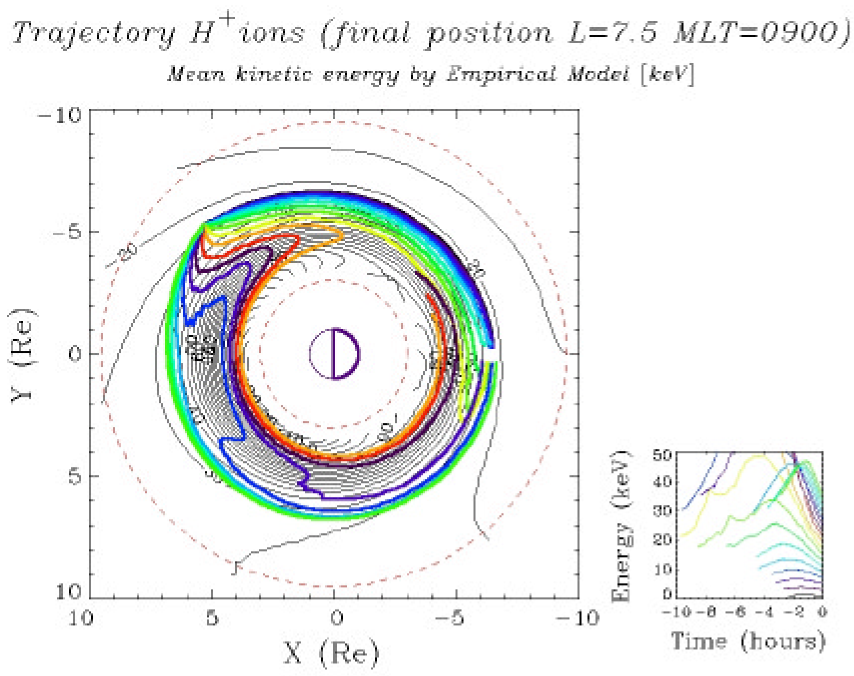


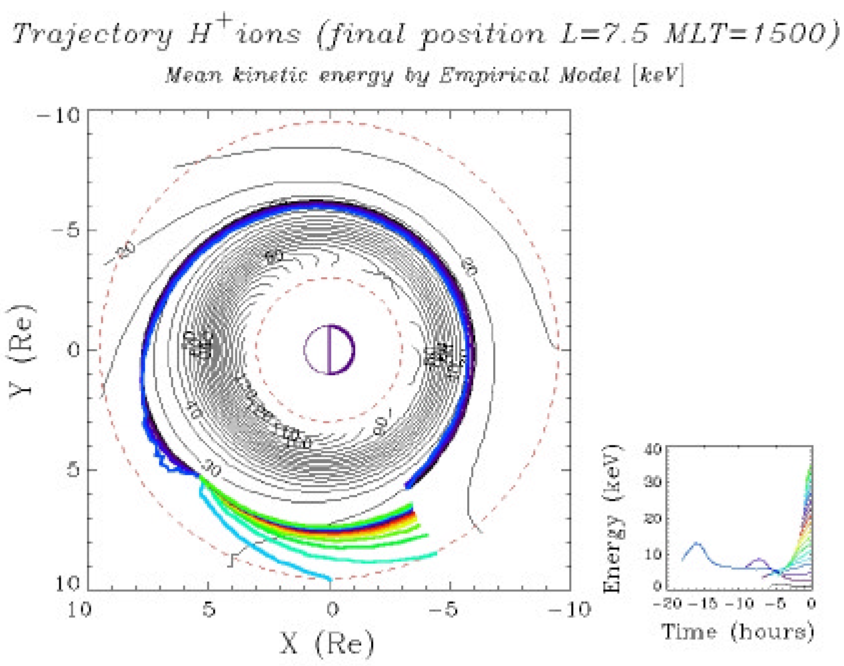


DAY-SIDE GAP

In the dayside magnetosphere, at energies of a few keV, the modelled fluxes are significantly attenuated (fig. 1). These flux decreases or gaps strongly vary with MLT, occurring at higher and lower energies in the dawn and dusk sectors, respectively.

In **Fig. 13** the backward trajectories of particles at different energies are traced from MLT=0900 and 1500. The resident time picks around the energy of the flux decreases (see fig 1).





Such features are in good agreement with in-situ measurements both at high latitudes (e.g., Kovrazhkin et al., 1999) or near the equator (e.g. McIlwain, 1972). In the dayside sector, such gaps likely are due to enhanced (larger than the ion lifetime) residence times in the magnetosphere (e.g. Kovrazhkin et al., 1999) rather than to an inward limit of penetration from the magnetotail or transition from open to closed orbits (e.g. Shirai et al., 1997).

CONCLUSIONS

This empirical model seems to well reproduce the fundamental properties of the quiet time equatorial magnetosphere.

The guess of the electric field configuration during quiet time are in good agreement with the empirical electric field model by McIlwain.

The analysis of particle trajectories in this AMPTE based convection pattern suggests a source of low-energy plasma in the afternoon-dusk sector as well as a flux depletion due to not allowed trajectories near L =5 for energies of the order of 50 keV, which is consistent with in-situ measurements.

The MLT dependent flux gap observed in the dayside around energies of few keV is well explained by the analysis of the residence times.

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